Changes of soil organic carbon and nitrogen in forage grass fields, citrus orchard and coniferous forests

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Abstract: Dynamic quantitative assessment of soil organic C and N is an available approach to understand the exact impact of land management on soils fertility. In this study the biomass of plants and content of soil organic C and N were compared in four typical land use systems which were planted with Ryegrass (*Lolium multiflorum* Lam.), Bahiagrass (*Paspalum notatum* Flugge.), Citrus (*Citrus reticulata* Blanco.), and Masson pine (*Pinus Massoniana* Lamb.) during 10 years in south China. Although biomass of plants in these four land use systems was nearly at the same level in the former investigation, total biomass for Ryegrass (RG), Bahiagrass (BG) was 3.68 and 3.75 times higher than that for Citrus (CT), and 2.06 and 2.14 times higher than that for Masson pine (MP) over 10 years of cultivation, respectively. Especially, underground total biomass for both RG and BG was over 10 times larger than that for CT and MP, indicating that forage grasses was much more beneficial to increase organic C and N storage in soils than CT and MP. The change content of soil organic C and N mainly occurred within soil depth of the 0-40 cm. The increased content of soil organic carbon and nitrogen was for 1.5 $t \cdot hm^{-2}$ and 0.2 $t \cdot hm^{-2}$ in the soil with planting RG and BG, and was for 1.2 $t \cdot hm^{-2}$ and 0.02 $t \cdot hm^{-2}$ in the soil with planting CT. An average loss was for 0.4 $t \cdot hm^{-2}$ and 0.04 $t \cdot hm^{-2}$ in the soil with planting MP during 10-year period.

Keywords: Soil organic carbon; Soil organic nitrogen; Dynamic change; Land use; Quantitative assessment

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Introduction

The soil organic carbon (C) and nitrogen (N) play key roles in soil conservation, agricultural production, and global environmental changes (Gregorich *et al.* 1994). Land use and management practices have great influence on soil organic C and N levels in soils (Lal 1995). Many studies, especially on subtropical regions, indicated that the soil organic C and total N decreased rapidly during the first 10 to 30 years of cultivation, and the rate of decline then slow down and the levels reach an equilibrium after approximately 60 years (Rusmussen *et al.* 1998). The equilibrium level of soil N and C depended on the productivity variables, climate, plant, soil, and management (Jenny 1980). Anyway, the rate and direction of changes of soil organic C and N were affected by different land use systems, management practices and initial soil organic C levels after the virgin soils were cultivated (Aggangan *et al.* 1998). Therefore, it is necessary to know the rate of changes of soil organic C and N under different cropping systems for developing sustainable strategies of soil use and management (Franzluebbers *et al.* 1996).

Extensively uncultivated soil in slope land in south China has been reclamated in recent decades. South China with a humid subtropical climate was a major region for agricultural production, which covered an area of 2.2 million km^2, but hills and mountains occupied 80% of the total land area. In general, due to the strong weathering, leaching during the soil formation and the destroying to the native forests from people, the soil of this region had a low level of fertility and suffered degradation. With the increase of population, how to effectively use and conserve soil became one of the biggest problems in China (Wang 1995). Coniferous forest and orchards have been emphasized before, but the economy benefits were not available, because of increased soil erosion (Wang 1995). In recent years, researchers found that forage grass was effective to stop soil erosion and increase soil fertility. However, the change of soil organic C and N contents by different land use was still unclear, which influenced development of economy and conversion soil fertility in this region.

The objective of this study was to determine the changing rate and change direction of soil organic C and N after the virgin soils were reclamated into different land use systems during 10 years in south China.

Materials and methods

Study site

The study was conducted at the Qianyanzhou Experimental Station of the Chinese Academy of Sciences, which

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is located at 26°44'48N, 115°04'13E with a subtropical climate, elevations from 66 to 131.5 m and an area of 204.2 hm^{-2}. The mean annual temperature is 18.6 °C and the annual precipitation is about 1360 mm. According to the Chinese soil taxonomic classification (Gong 1995), the soils are classified into four soil groups and fifty species. The four soil groups are Red soils, Paddy soils, Meadow soils, and Umbrihumus Meadow soils, which approximately correspond to the Haplic Acrisols, Aric Anthrosols, Eutric Fluvisols and Umbric Fluvisols, respectively, in the FAO-UNESCO WORLD MAP Revised Legend.

Experiment and analysis

This study was conducted in the long-term monitoring experimental plot, each area of 200 m^2 was selected in four land use systems with planting Ryegrass (*Lolium multiflorum* Lam.), Bahiagrass (*Paspalum notatum* Flugge.), Citrus (*Citrus reticulata* Blanco.), and Masson pine (*Pinus Massoniana* Lamb.) for three replications. Plant residues, organic fertilizers, and their decomposition rate as well as the total biomass of the plants were investigated and determined in the experimental plots. The samples of soils and plants were collected for analyzing total biomass of plants, the contents of soil organic C and N at the soil depth of 0-20, 20-40, and 40-60 cm. Storage of soil organic C and N were calculated by the following equations:

$$S_C = C_C B_S D_S A_S \tag{1}$$

$$S_N = C_N B_S D_S A_S \tag{2}$$

where, S_C and S_N is the storage of carbon and nitrogen, respectively. C_C and C_N is the content of soil carbon and nitrogen, respectively. B_S is the bulk density of the soils. D_S is the soil depth, and A_S is soil area.

The content of soil organic C was determined by using the potassium dichromate-sulfuric acid oxidation method, and the content of soil organic N was determined by using Kjeldahl Method (ISSAS 1978).

The Tukey's test was used to test the biomass of plants, the content of soil organic C and N. And the LSD was calculated to compare the differences between average values of those in four types of land use systems.

Results and discussion

Biomass and plant residues

As shown in Table 1, no significant difference of plants biomass was observed among cultivation systems with Ryegrass (RG), Bahiagrass (BG), Citrus (CT) and Masson pine (MP) in the former investigation. However, over 10 years of cultivation, total biomass in two forage grass cultivation systems with ryegrass (RG) and Bahiagrass (BG), was much higher than that in citrus orchard (CT) and Masson pine forest (MP). In the experimental case, total biomass in cultivation systems with RG and BG was 3.68 and 3.76 times higher than that with CT, 2.06 and 2.14 times higher than that with MP, respectively.

Table 1. Total biomass production under different land use systems (10^3 kg·hm^{-2})

Plants in land use	Aboveground		Underground		Total	
	FI	LI	FI	LI	FI	LI
Ryegrass	2.73a	43.51b	3.71a	88.70a	6.45a	132.21a
Bahiagrass	2.81a	45.11b	3.83a	90.22a	6.64a	135.33a
Citrus	3.02a	31.43c	4.11a	4.53b	7.31a	35.96c
Masson pine	2.93a	56.64a	3.66a	6.51b	6.59a	63.15b

Notes: FI: in the former investigation; LI: in the latter investigation; Average values followed by the same letter in the table are not different at α = 0.05 using LSD test.

Underground total biomass in cultivation systems with RG and BG was almost 19 times heavier than that with CT, and 13 times than that with MP, which was very important for soil conservation and beneficial improvement of soil organic matter, indicating that soil organic C and N input from the residues of BG and RG were much more than that from CT and MP (Table 2). The soil organic C and N inputs to natural managed ecosystem affect the microbe activities, nutrients as well as physical characteristics, which are closely related to its fertility maintaining and resistance against runoff and erosion.

Table 2. Residues and input of organic C and N in different land use systems in the former investigation

Plants in land use	Residues							Organic C	Organic N
	Leaf	Stem	Fruit	Bark	Root	Branch	Total		
Ryegrass	0.51c	0.91	-	-	8.87a	-	10.29a	4.16a	0.13a
Bahiagrass	0.90c	1.10	-	-	9.02a	-	11.02a	4.52a	0.14a
Citrus	3.41a	-	1.01	-	0.41b	0.30	5.13b	2.22b	0.06b
Masson pine	1.74b	-	0.61	0.16	0.36b	1.19	4.06b	1.97b	0.03b

Notes: Average values followed by the same letter in the table are not different at α = 0.05 using LSD test.

So far, Citrus is widely planted in south China, which is one of the most important cash crops for farmers living there. Coniferous trees are usually planted extensively in hilly regions in subtropical China as the pioneer (i.e., early established) tree species because of their fast growth even on poor soils. However, because of small underground biomass production of planting citrus trees and coniferous trees, the soil organic matter (SOM) of citrus trees only showed a very slight improvement for annually applied organic fertilizer, while SOM of Mason pine forestry represented a decrease trend over 10 years experiment (Wang 1995).

Contents of soil organic C and N

Soil organic C and N, which play a mostly beneficial role in determining the biological, physical, and chemical quality in the soil, are important nutrients for soil organisms and plants (Stevenson 1994). There existed a positive relationship between contents of soil organic C and crops yield in many agroecosystems.

In the soil depth of 0-20 cm, the contents of soil organic C and N were greatly affected by land use systems, indicating that changes of contents of soil organic C and N obviously occurred in surface soil (Table 3). The contents of soil organic C and N increased in the soil with RG and BG, while decreased in the soil with CT and MP between the former investigation and the latter investigation. Land use systems also influenced the contents of soil organic C and N in soil depth of 20-40 cm, however, there was nearly no effect on the contents of soil organic C and N in 40-60 cm-layer. Mineralizable N (MN) increased and C/N ratio decreased in the soil with RG, BG and CT, but no significant changes in the soil with MP.

Table 3. Contents of soil organic C and N under different land use systems ($g \cdot kg^{-1}$)

Item	Land use	0-20 cm			20-40 cm			40-60 cm		
		FI	LI	Δv	FI	LI	Δv	FI	LI	Δv
organic carbon	RG	11.17a$^{1)}$	14.37a	3.20a$^{+2)}$	7.41a	10.10a	2.69a^{+}	4.83a	5.01a	0.18a
	BG	11.19a	14.48a	3.29a^{+}	7.17a	9.60a	2.43a	4.43a	4.62a	0.19a
	CT	11.04a	7.82c	-3.22c^{+}	7.55a	6.75b	-0.80b^{+}	4.53a	4.52a	-0.01a
	MP	11.07a	10.21b	-0.86b	7.26a	6.58b	-0.68b	4.75a	4.77a	0.02a
organic nitrogen	RG	0.89a	1.24a	0.35a^{+}	0.71a	0.99a	0.28a^{+}	0.52a	0.54a	0.02a
	BG	0.90a	1.30a	0.40a^{+}	0.68a	0.92a	0.24b^{+}	0.48a	0.50a	0.02a
	CT	0.82a	0.84b	0.02b	0.70a	0.66b	-0.04c	0.51a	0.50a	-0.01a
	MP	0.88a	0.85b	-0.03b	0.72a	0.64b	0.08c^{+}	0.56a	0.57a	0.01a
Miner-alizable N	RG	10.32a	45.21a	34.76a^{+}	10.89a	21.02b	10.13c^{+}	10.56a	10.89a	0.33b
	BG	12.30a	49.32a	37.02a^{+}	11.03a	23.51b	12.48b^{+}	10.17a	10.22a	0.05b
	CT	11.32a	48.21a	36.89a^{+}	10.21a	30.21a	20.00a^{+}	9.89a	10.21b	1.32a^{+}
	MP	12.38a	11.27b	-1.07b	9.96a	10.89c	0.93d	10.03a	10.36ab	0.33b
C/N	RG	12.55a	11.56a	-0.99ab^{+}	10.44a	10.53a	0.901b	9.29a	9.27a	-0.02a
	BG	12.43a	11.14a	-1.29b^{+}	10.54a	10.43a	-0.11ab	9.23ab	9.24ab	0.01a
	CT	13.46a	9.31b	-0.45c^{+}	10.79a	10.22a	-0.57b	8.88ab	9.04ab	0.16a
	MP	12.58a	12.01a	-0.57a	10.08a	10.28a	0.20a	8.48b	8.47b	-0.01a

Notes: Average values followed by the same letter in the table are not different at α = 0.05 using LSD test; "+" ---differences between the means of LI and FI are significant at α = 0.05 using LSD test; FI----in the former investigation; LI---in the latter investigation.

The storage of soil organic C and N of RG, BG, CT and MP under the land use systems were nearly at the same level in the former investigation (Table 4). However, Organic C and N increased in the soil with planting RG and BG at the soil layers of 0-20 cm and 20-40 cm, over 10 years of cultivation, whereas those with CT and MP decreased. Soil organic C and N storage under soil layers of 40 cm was nearly not affected during 10 years. In the present study, it is estimated that an average content of soil organic C and N increased 1.5 $t \cdot hm^{-2}$ and 0.2 $t \cdot hm^{-2}$ in soil with planting RG and BG, respectively. Whereas, an average loss of soil organic C and N was 1.2 $t \cdot hm^{-2}$ and 0.02 $t \cdot hm^{-2}$ in soil with planting CT and 0.4 $t \cdot hm^{-2}$ and 0.04 $t \cdot hm^{-2}$ in soil with planting MP over 10 years cultivation.

In this case, our results suggested that forage grass had a much better biomass as well as a better improvement in soil organic C and N in land use systems with RG and BG than that with CT and MP. However, forage grass systems have not been fully established yet, while orchards and coniferous trees have long been emphasized in South China. Therefore, in view of the sustainable management of citrus orchard, it is necessary to increase the organic fertilizer application in citrus orchards to keep the soil organic carbon level.

Table 4. Changes of storage of soil organic C and N in land use systems ($10^3 kg \cdot hm^{-2}$)

Item	Land use	0-20 cm			20-40 cm			40-60 cm		
		FI	LI	Δ_V	FI	LI	Δ_V	FI	LI	Δ_V
Bulk density	RG	1.35a	1.28b	-0.07bc⁺	1.42a	1.41a	-0.01a	1.51a	1.52a	0.01a
	BG	1.32a	1.29b	-0.03b⁺	1.39a	1.42a	0.03a	1.48a	1.50a	0.02a
	CT	1.36a	1.26b	-0.10c⁺	1.40a	1.41a	0.01a	1.52a	1.52a	0.00a
	MP	1.34a	1.36a	0.02a	1.40a	1.39a	-0.01a	1.49a	1.53a	0.04a
organic carbon	RG	30.16a	36.79a	6.63a⁺	21.04a	28.48a	7.44a⁺	14.59a	15.23a	0.64a
	BG	29.54a	37.36a	7.82a⁺	19.93a	27.26a	7.33a⁺	13.11b	13.86b	0.75a
	CT	30.02a	19.71c	-10.31c⁺	21.14a	19.03b	-2.11b⁺	13.77ab	13.74b	-0.03b
	MP	29.67a	27.77b	-1.90b	20.33a	18.29b	-2.04b⁺	14.59ab	14.59ab	0.43ab
organic nitrogen	RG	2.40a	3.17a	0.77b⁺	2.02a	2.79a	0.77a⁺	1.64a	1.64a	0.07a
	BG	2.38a	3.35a	1.03a⁺	1.89a	2.61a	0.72a⁺	1.50a	1.50a	0.08a
	CT	2.23a	2.12ba	-0.11c	1.96a	1.90b	-0.06b	1.52a	1.52a	-0.03a
	MP	2.36a	2.31b	-0.05c	20.02a	1.78b	-0.24b	1.74a	1.74a	0.07a

Notes: Mean values followed by the same letter in the table are not different at α = 0.05 using LSD test.; "+" ---- differences between the means of LI and FI are significant at α = 0.05 using LSD test; FI----in the former investigation; LI----in the latter investigation.

Conclusions

Coniferous forests, economic orchards, and forage grass fields were three major land use systems for developing economy and conserving soils fertility in South China. Total plant biomass of RG and BG was 3.5 and 2 times larger than that of CT and MP, respectively. Total root biomass of RG and BG was respectively about 20 times heavier than that of CT and over 10 times of that of MP.

Significant change of content of soil organic C and N was mainly observed within soil depth of 0-40 cm, especially in the surface soil (0-20 cm). Comparison of the contents of organic carbon and nitrogen under different land use systems over 10 years showed that forages grass played a much better role in total biomass production than citrus orchard and coniferous forest. In this experiment, an average content of soil organic C and N increased 1.5 $t \cdot hm^{-2}$ and 0.2 $t \cdot hm^{-2}$ in the soil with planting RG and BG, respectively. Whereas, an average loss of soil organic C and N was 1.2 $t \cdot hm^{-2}$ and 0.02 $t \cdot hm^{-2}$ in the soil with planting CT and 0.4 $t \cdot hm^{-2}$ and 0.04 $t \cdot hm^{-2}$ in the soil with planting MP over 10 years cultivation.

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